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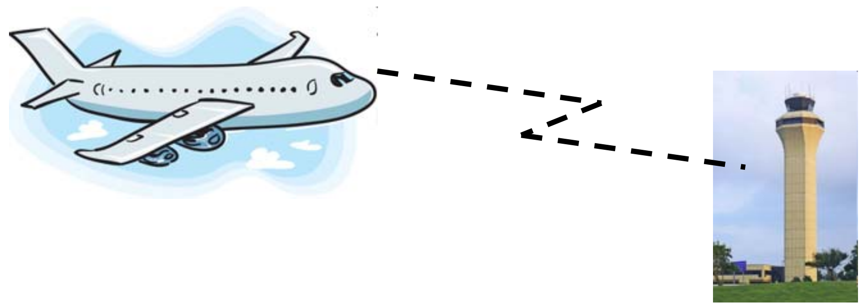
Analysis of L-Band Digital Aeronautical Communication Systems: L-DACS1 and L-DACS2



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on Unmanned Aircraft Systems

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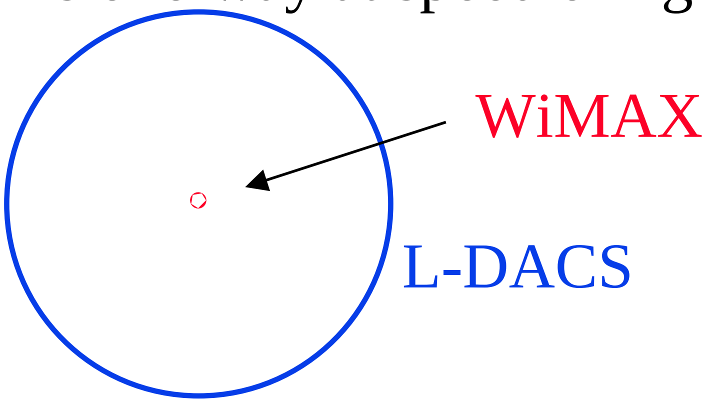
Overview

- Aeronautical Datalink Issues
- L-Band Digital Aeronautical Communication System (L-DACS)
- Interference Analysis and Interference Mitigation
- Performance Requirements

RTCA Aeronautical Datalinks: Challenges

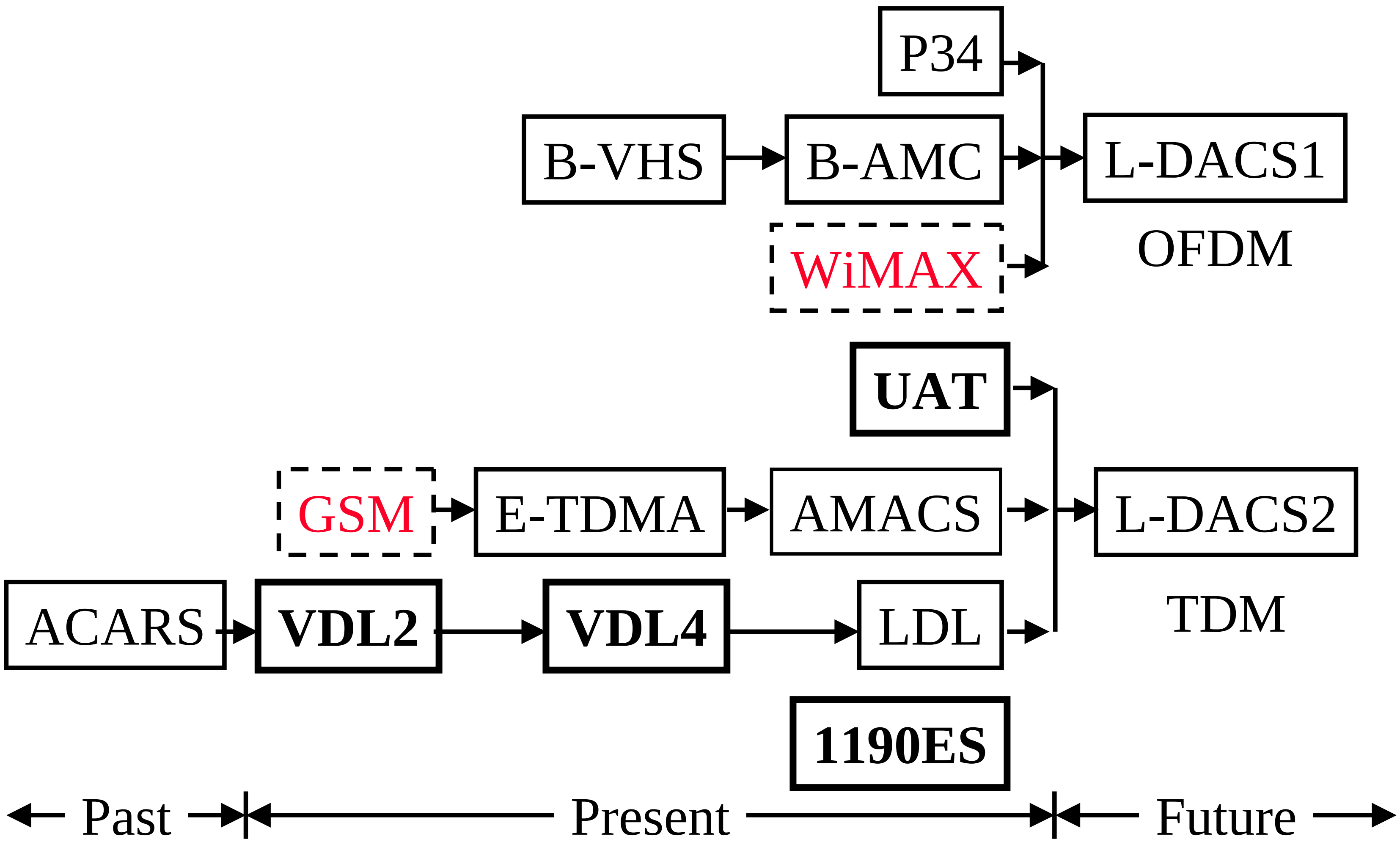
- Very long distances:
  - WiFi covers 100 m
  - WiMAX cells are 1km in urban and 3 km in suburban areas
  - L-DACS needs to cover 360 km (200 nautical miles)
    - Limited Power ⇒ High bit error rate or very low data rate ⇒ Low Spectral efficiency (2 bps/Hz is a challenge)
    - Long turn-around times ⇒ Large guard times (360 km = 1.2 ms one-way at speed of light)



Datalinks Challenges (Cont)

- Very High Mobility:
  - WiFi isn’t designed for mobility
    (200m at 60km/h = 12s between handovers)
  - WiMAX is optimized for 0-10 km/h, operates up to 120 km/h
  - L-DACS has to operate up to 600 nm/h (1080

Aeronautical Datalinks



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Aeronautical Datalinks (Cont)

- ACARS: Aircraft Communications Addressing and Reporting System. Developed in 1978. **VHF** and **HF**. Analog Radio
- VDL2: Digital link. In all aircrafts in Europe. 1994. VHS.
- VDL4: Added Aircraft-to-Aircraft. 2001. Limited deployment
- LDL: **L-Band** Digital Link. TDMA like GSM.
- E-TDMA: Extended **TDMA**. Hughes 1998. **Multi-QoS**
- AMACS: All purpose Multichannel Aviation Communication System. 2007. L-Band. Like GSM and E-TDMA.
- UAT: 981 MHz. 2002. One 16B or 32B message/aircraft/sec
- P34: EIA/TIA Project 34 for public safety radio. Covers 187.5 km. L-Band.
- B-VHS: MC-CDMA (**OFDMA**+CDMA). VHF. TDD.
- B-AMC: Broadband Aeronautical Multicarrier System. OFDMA. B-VHS in L-Band.

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Issue 1: Spectrum

- Lower frequencies are more crowded.
  HF (3-30MHz) is more crowded than VHF (30-300MHz).
  VHF is more crowded than L-band.
- Higher frequencies have more bandwidth and higher data rate
  $\Rightarrow$ Trend: Move up in Frequency
- Effect of Frequency on signal:

$$P_R = P_T G_T G_R \left(\frac{\lambda}{4\pi d}\right)^2$$

- Attenuation $\propto$ (frequency)^2(distance)^2
  $\Rightarrow$ Lower Frequencies have lower attenuation,
  e.g., 100 MHz has 20 dB less attenuation than 1GHz
  $\Rightarrow$ Lower frequencies propagate farther
  $\Rightarrow$ Cover longer distances

Spectrum (Cont)

- Doppler Shift = velocity/wavelength
  ⇒ Lower frequencies have lower Doppler shift
  Higher Frequencies not good for high-speed mobility
  Mobility ⇒ Below 10 GHz
- Higher frequencies need smaller antenna
  Antenna ≥ Wavelength/2, 800 MHz ⇒ 6”
- Higher frequencies are affected more by weather
  Higher than 10 GHz affected by rainfall
  60 GHz affected by absorption of oxygen molecules

Overview

1. Aeronautical Datalink Issues
2. L-Band Digital Aeronautical Communication System (L-DACS)
3. Interference Analysis and Interference Mitigation
4. Performance Requirements

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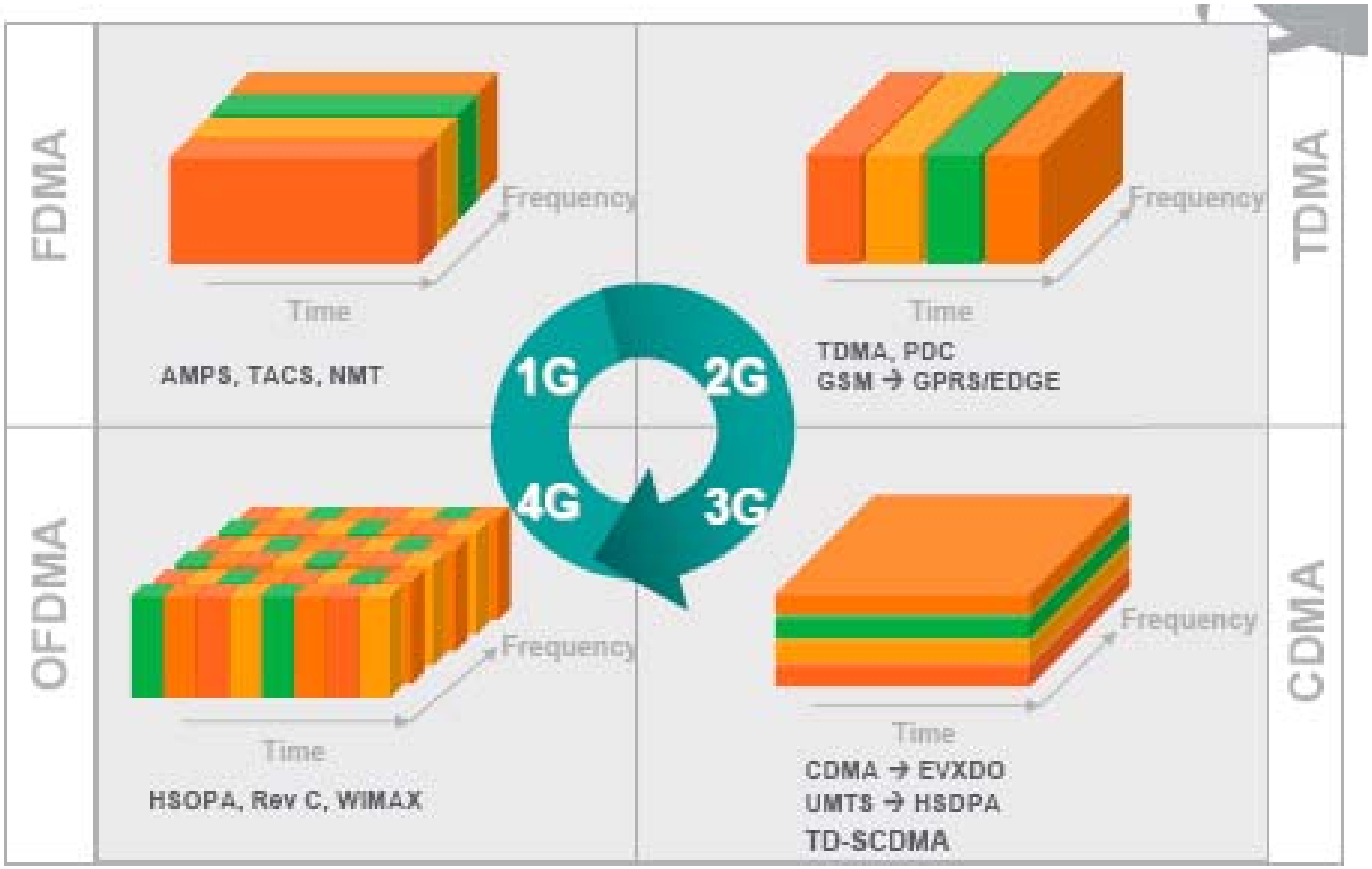
L-DACS: Common Features

- L-band Digital Aeronautical Communications System
- Type 1 and Type 2
- Both designed for Airplane-to-ground station communications
- Airplane-to-airplane in future extensions
- Range: 200 nautical miles (nm)
  (1 nm =1 min latitude along meridian = 1.852 km =1.15 mile)
- Motion: 600 knots = 600 nm/h = Mach 1 at 25000 ft
- Capacity: 200 aircrafts
- Workload: 4.8 kbps Voice+Data
- All safety-related services
- Data=Departure clearance, digital airport terminal information, Oceanic clearance datalink service

Issue 2: Modulation and Multiplexing

- Modulation:
  - Single Carrier
  - Multi-carrier
- Multiplexing:
  - Time division
  - Frequency division
  - Code division
  - Orthogonal Frequency Division

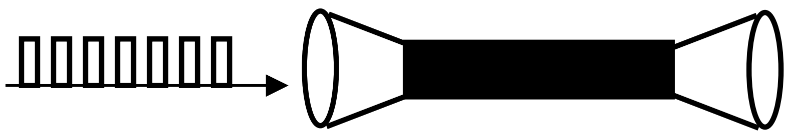
Cellular Multiple Access Methods

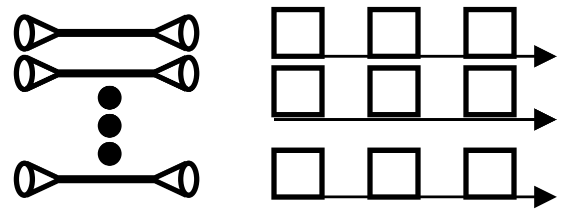


Source: Nortel

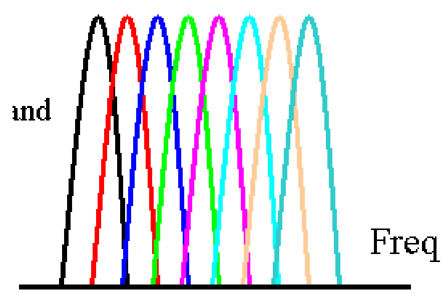
OFDMA

- Orthogonal Frequency Division Multiple Access
- Ten 100 kHz channels are better than one 1 MHz Channel
  ⇒ Multi-carrier modulation





- Frequency band is divided into 256 or more sub-bands.
  Orthogonal ⇒ Peak of one at null of others
- Each carrier is modulated with a BPSK, QPSK, 16-QAM, 64-QAM etc depending on the noise (Frequency selective fading)
- Used in 802.11a/g, 802.16,
  Digital Video Broadcast handheld (DVB-H)
- Easy to implement using FFT/IFFT



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L-DACS1

- OFDMA: Similar to WiMAX
- Multi-carrier: 50 carriers 9.76 kHz apart
- Use two channels of 498 kHz each

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L-DACS2

- Based on GSM
- GSM PHY, AMACS MAC, UAT Frame Structure
- Uses Gaussian Minimum Shift Keying (GMSK) modulation as in GSM
- GSM works at 900, 1800, 1900 MHz
  $\Rightarrow$ L-DACS2 is in lower L-band close to 900MHz
- Tested concept
- Price benefit of GSM components
- Uses basic GSM not, later enhanced versions like EDGE, GPRS, …
  These can be added later.

Ref: http://en.wikipedia.org/wiki/Gaussian_Minimum_Shift_Keying#Gaussian_minimum-shift_keying

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Single vs. Multi Carrier

- WiMAX, 11a/g/n use OFDM
- Advantages of OFDM:
  - Graceful degradation if excess delay
  - Robustness against frequency selective burst errors
  - Allows adaptive modulation and coding of subcarriers
  - Robust against narrowband interference (affecting only some subcarriers)
  - Allows pilot subcarriers for channel estimation

RTCA L-DACS1: OFDM Parameters

- Subcarrier spacing: 9.76 kHz = Similar to WiMAX
- Guard Time Tg = 17.6 μs = 5.28 km

Parameter	**Value**
Channel bandwidth B	498 kHz
Length of FFT Nc	64
Used sub-carriers	50
Sub-carrier spacing (498/51 kHz) f	**9.76 kHz**
OFDM symbol duration with guard Tog	120 μs
OFDM symbol duration w/o guard To	102.4 μs
Overall guard time duration Tg	**17.6 μs**
OFDM symbols per data frame Ns	54

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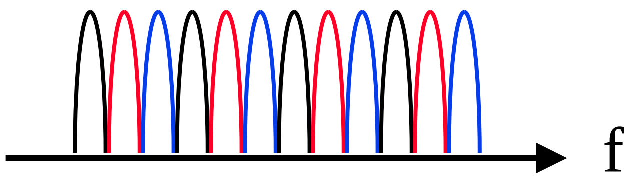
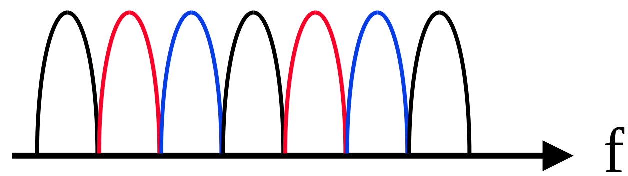
L-DACS1 Design Decisions

- Large number of carriers ⇒ Reduced subcarrier spacing ⇒ Increased inter-carrier interference due to Doppler spread

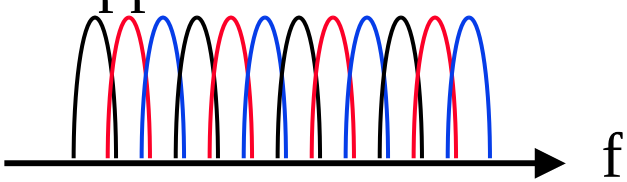
10 kHz spacing



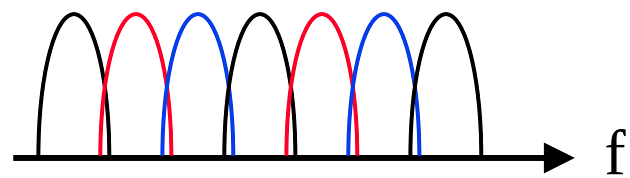
20 kHz spacing



- Doppler causes carrier frequency shift:



May not be acceptable



Acceptable

- WiMAX use 10 kHz spacing
- Long Term Evolution (LTE) uses 15 kHz spacing to meet faster mobility

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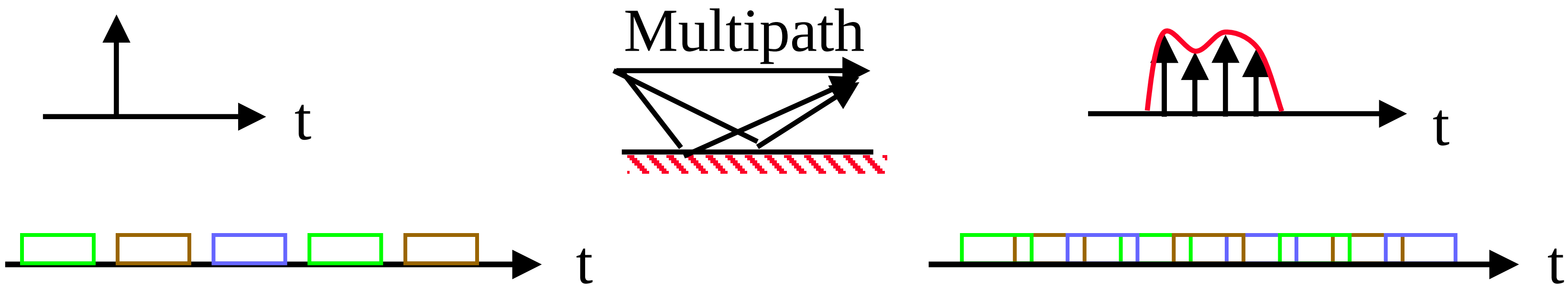
L-DACS1 Design Decisions

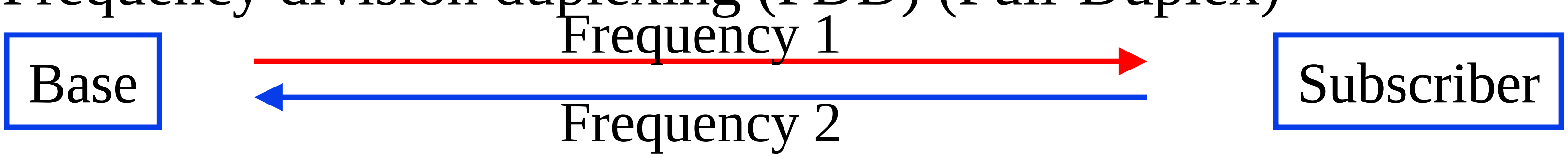
- Multipath causes symbols to expand:



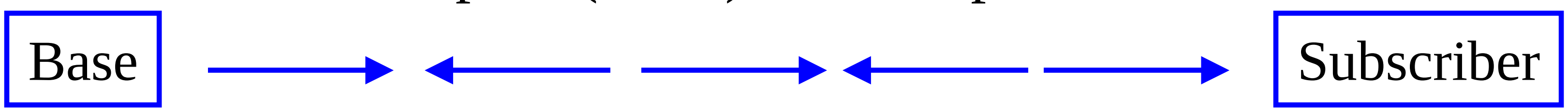
- Guard time duration Tg (Cyclic prefix) is designed to overcome this delay spread.
- 17.6 μs = 5.8 km path differential in L-DACS1
- LTE is designed with two CP lengths of 4.7 μs, 16.7 ms, and 33.3 ms (1.4km, 5 km, 10 km).

RTCA Issue 3: Duplexing (TDD vs. FDD)

- L-DACS1 is FDD, L-DACS2 is TDD.
- Duplex = Bi-Directional Communication
- Frequency division duplexing (FDD) (Full-Duplex)



- Time division duplex (TDD): Half-duplex



- Most WiMAX/LTE deployments will use TDD.
  - Allows more flexible sharing of DL/UL data rate Good for data
  - Does not require paired spectrum
  - Easy channel estimation ⇒ Simpler transceiver design
  - Con: All neighboring BS should synchronize

Duplexing (cont)

- L-DACS1 FDD selection seems to be primarily because 1 MHz contiguous spectrum may not be available in L-band.
- Possible solution: Carrier-bonding used in the WiMAX v2 and in LTE

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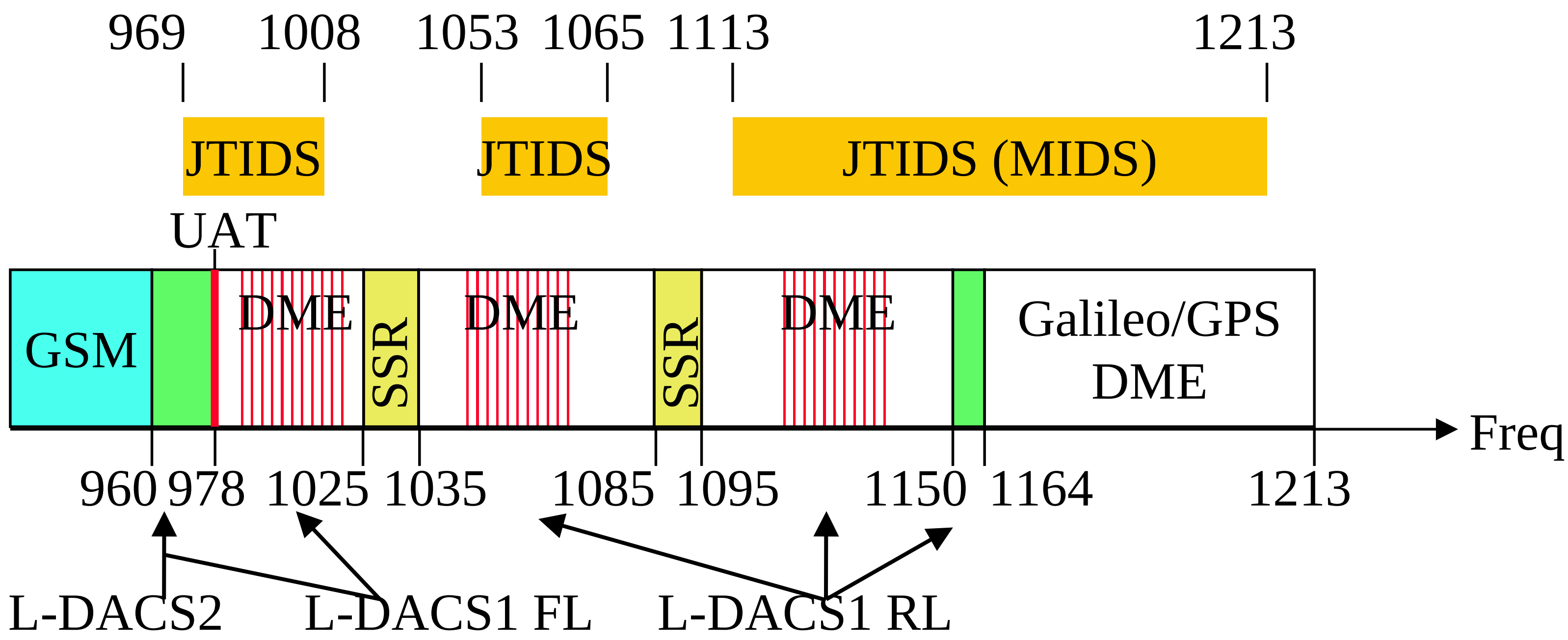
L-Band Spectrum Usage



- L-DACS1 ⇒ 2x498.5 kHz FL in 985.5-1008.5MHz, RL in 1048.5-1071.5MHz, Duplex spacing 63 MHz

DME=Distance Measuring Equipment
JTIDS=Joint Tactical Information Distribution System
MIDS=Multifunction Information Distribution System
SSR=Secondary Surveillance Radar
GSM=Global System for Mobile Communications

- L-DACS2 ⇒ One 200 kHz channel in lower L-Band 960-975 MHz

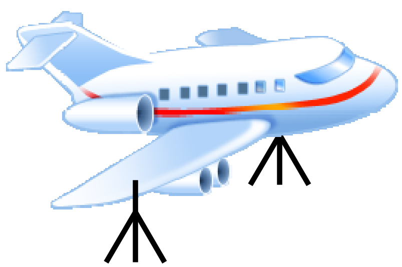
Issue 4: Interference

Interfering Technologies:

1. Distance Measurement Equipment (DME)
2. Universal Access Transceiver (UAT)
3. 1090 Extended Squitter (ES)
4. Secondary Surveillance Radar (SSR)
5. Joint Tactical Information Distribution System (JTIDS)
6. Groupe Speciale Mobile (GSM)
7. Geostationary Navigation Satellite System (GNSS)

DME

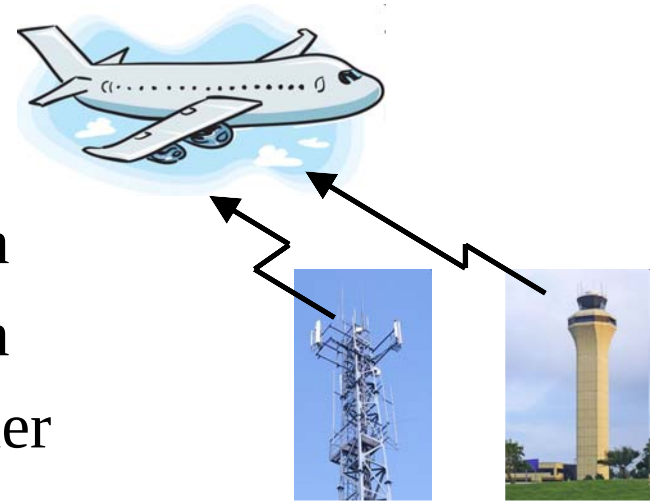
- Distance Measuring Equipment
- Ground DME markers transmit 1kW to 10 kW EIRP.
- Aircraft DME transmits 700W = 58.5 dBm
- Worst case is Aircraft DME to Aircraft L-DACS



	L-DACS
AS DME XMTR Power	58.5 dBm
Path loss	-35 dB
Net Interference	23.5 dBm

- Same side of the aircraft or small aircrafts
  $\Rightarrow$ Even 35 dB isolation results in +23.5 dBm
- Need to design coordination

GSM Interference



- Maximum allowed EIRP 62 dBm
  - 43 dB power + 19 dBi Antenna gain
  - 37 dB power + 25 dBi Antenna gain
- -80 dBc power at 6 MHz from the carrier
- GSM Interference:
  - L-DACS1 = -22dBm
  - L-DACS2= -10.8 dBm
    (L-DACS2 uses a band close to GSM)

Bluetooth and WiFi Coexistence

- Bluetooth frequency hops in 1 MHz carriers over 2402 - 2480 MHz (79 MHz total)
- WiFi uses OFDM with 52 subcarriers in 20 MHz channels in 2402-2480 MHz (3 non-overlapping channels)
- Most computers have both Bluetooth and WiFi
- Collaborative Strategies: Two networks on the same device
- Non-Collaborative Strategies: No common device

Collaborative Coexistence Strategies

- Both networks on the same equipment (Laptop or IPhone):
  1. Time Division: Bluetooth skips slots when WiFi is busy, WiFi reserves time for Bluetooth between Beacons
  2. Packet Traffic Arbitration: Packets are prioritized and queued on a common queue for transmission
  3. Notch Filter: WiFi OFDM does not use subcarriers to which Bluetooth hops

RTCA Non-Collaborative Coexistence Strategies

- Measure noise level and error rate:
  Random bit errors $\Rightarrow$ Noise

1. Adaptive Packet Selection: Bluetooth uses coding (FEC and Modulation) depending upon interference. Use FEC only if noise. No FEC if interference.
2. Master Delay Policy: Bluetooth keeps track of error rates on various frequencies. Refrains from transmission on frequencies where interference is high
3. Adaptive frequency hoping: Hop over only good frequencies
4. Adaptive Notch Filter on WiFi

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Performance Requirements

- Peak Instantaneous Aircrafts Counts (PIACs):

Region	Year	APT	TMA	ENR	ORP
Europe	2020		16	24	
US	2020	200		41	10
Europe	2030		44	45	
US	2030	290		95	34

APT = Airport

TMA = Terminal Maneuvering area

ENR = En route

ORP = Oceanic/Remote/Polar

AOA = Autonomous Operations Area

Ref: Communications Operating Concepts and Requirements (COCR) V2

RTCA Performance Requirements (cont)

- Maximum Airspeed in Knots True Air Speed (KTAS)

	APT	TMA	ENR	ORP	AOA
Phase 1	160	250	600	600	
Phase 2	200	300	600	1215	540

- Most stringent capacity requirements in kbps:

Phase	APT	TMA	ENR EU	ENR US	ORP	AOA
Phase 1	30	8	15	20	5	
Phase 2	200	40	150	200	40	100

- Phase 2 begins in 2020. Requirements seem too low.

Data Rate

- L-DACS1: QPSK1/2 - 64-QAM 3/4
  ⇒ FL (303-1373 kbps)+ RL (220-1038 kbps) using 1 MHz
  ⇒ Spectral efficiency = 0.5 to 2.4 bps/Hz
- L-DACS2: 270.833 kbps (FL+RL) using 200 kHz
  ⇒ Spectral efficiency = 1.3 bps/Hz
  (Applies only for GSM cell sizes)
  Signal to noise ratio decreases by the 2nd to 4th power of distance

Summary

	L-DACS1	L-DACS2
Modulation	√OFDM	Single Carrier
Spectral efficiency	√0.5-2.3 bps/Hz	1.3 bps/Hz
Spectrum Flexibility	√Entire L-Band	Lower L-Band
Duplexing	FDD	√TDD

1. SS Radar, DME, UAT, and L-DACS from the same plane will require some co-ordination technique to be developed
2. GSM base stations located near the airport can seriously interfere with L-DACS
3. L-DACS1 has better chances of coexistence because of OFDM
4. Need to extend known coexistence strategies to L-DACS
5. No independent analysis/verification of the two proposals

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